Treatment plant design using natural products for the purification of surface waters in Burkina Faso

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Diseño de plantas de tratamiento el uso de productos naturales para la purificación de aguas superficiales en Burkina Faso

Disseny de plantes de tractament l'ús de productes naturals per a la purificació de aigües superficials a Burkina Faso

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RESUMEN

La climatología semi-árida de Burkina Faso (África occidental) es propensa a variaciones estacionales extremas, encadenando largos periodos de sequía con fuertes lluvias concentradas entre los meses de mayo y octubre. Las deficiencias tanto en el suministro de agua como en su calidad, especialmente en zonas rurales, supone la principal causa de enfermedades causadas por parásitos intestinales, con particular incidencia en la población infantil.
Este estudio está localizado en una zona rural al norte del distrito de Yako, donde una de cada tres familias no tiene acceso a agua potable. Se centra en el tratamiento de agua mediante la utilización de semillas de la planta *moringa oleífera* (introducida en el país por comerciantes siglos atrás) como coagulante natural para la eliminación de la turbidez y de las partículas en suspensión de las aguas superficiales. A este tratamiento le sigue un proceso de desinfección química con cloro generado *in situ* vía electrólisis utilizando una fuente autónoma de suministro eléctrico.
Se propone un sistema sostenible de purificación de agua el cual puede sustituir reactivos químicos por productos naturales mediante el empleo de un proceso eficiente energéticamente y de fácil operación.

Palabras clave: Agua potable; Burkina Faso; Cloro electro generado; Coagulante natural; Moringa Oleifera; Turbidez.

SUMMARY

The semi-arid climatology of Burkina Faso (Western Africa) is prone to extreme seasonal variations, chaining long periods of drought with heavy rainfalls concentrated between to the months of May and October. Deficiencies in both water supply and quality, especially in rural areas, comprise the main cause of illness derived from intestinal parasites, with particularly high incidences in the infantile population.
This study is based in the rural area of the northern district of Yako, an area where one of every three families does not have access to potable water. It is centered on the treatment of fresh water by using the seeds of the plant *moringa oleifera* (introduced to the country by traders centuries ago) as a natural coagulant for the elimination of turbidity and suspended particles in fresh surface waters. This treatment is followed by chemical disinfection with chlorine generated *in situ* via electrolysis using an autonomous electrical power supply.
A sustainable water purification system is thus proposed which can substitute the use of chemical reagents with natural products by employing a process which is both energy efficient and easy to operate.

Key words: Potable water; Burkina Faso; Chlorine electro-generated; Moringa Oleifera; Natural coagulant; Turbidity.

RESUM

La climatologia semi-àrida de Burkina Faso (Àfrica occidental) és propensa a variacions estacionals extremes, encadenant llargs períodes de sequera amb fortes pluges concentrades entre els mesos de maig i octubre. Les deficiències tant en el subministrament d'aigua com en la seva qualitat, especialment en zones rurals, suposa la principal causa de malalties provocades per paràsits intestinals, amb particular incidència en la població infantil.
Aquest estudi està localitzat en una zona rural del nord del districte de Yako, a on una de cada tres famílies no té accés a l'aigua potable. Se centra en el tractament de l'aigua mitjançant la utilització de llavors de la planta *moringa oleífera* (introduïda al país per comerciants segles enrere) com a coagulant natural per a l'eliminació de la terbolesa i de les partícules en suspensió de les aigües superficials. Aquest tractament és seguit per un procés de desinfecció química amb clor generat in situ via electròlisi utilitzant una font autònoma de subministrament elèctric.
Es proposa un sistema sostenible de purificació d'aigua que pot substituir reactius químics per productes naturals mitjançant l'ús d'un procés eficient energèticament i de fàcil operació.

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Paraules clau: Aigua potable; Burkina Faso; Clor electro generat; Coagulant natural; Moringa Oleifera; Terbolesa.

1. INTRODUCTION

Burkina Faso is located in semi-arid West Africa with a human development index (HDI) of 0.330, it is currently ranked in position 173 out of 176 countries in terms of development, with a per capita income of $1,200 per year [1]. Of the active population, 92% base their livelihood on agricultural production and the literacy rate barely reaches 26.6% [2]. Burkina Faso has a climate which is prone to extreme seasonal variations, linking long periods of drought between November and April with heavy rainfall concentrated in the months of May and October. In general, there has been a gradual decrease in annual rainfall in recent years. However, studies carried out by both public and private organizations agree that the problems faced as a result of deficiencies in water quantity and quality are more of a direct consequence of resource mismanagement than mere scarcity.

Concerning water quality, diarrheal diseases are responsible for 16% of the cases of infant mortality worldwide [3] In Burkina Faso, particularly in rural areas, diarrheal disease and diseases associated with intestinal parasites are the leading cause of infant mortality as a result of the ingestion of unsafe water. This phenomenon is directly correlated to the fact that one in every three households in the country does not have access to a reliable supply of drinking water. The authorities of the district of Yako recognize the fact that the limitations of the local health infrastructure and the lack of potable water comprise the principal concerns of the community, particularly in those villages located on the outskirts of the municipality of Yako.

In recent years the local development entity BERACIL, in collaboration with the development council of Yako, has been leading an agro economic development program in the municipality of Yako by way of the cultivation of the tropical tree, *moringa oleifera* (known locally as *Arzaan Tiiga* or ´Tree from Heaven´ in the autochthonous language, Mooré). The fibrous powder generated by grinding the seeds of *moringa oleifera* can be used, among others applications, as a natural coagulant-flocculant in the phase of suspended solid elimination of conventional water purification processes [4-8](Ndabigengesere and Narasiah, 1998; Ghebremichael et al., 2005; Amagloh and Benang, 2009; Pritchard et al., 2010; Yin, 2010). This application is particularly relevant for surface waters, as in the case of fresh water reservoirs, which typically have turbidity levels significantly higher than groundwater water extracted via perforated wells.

One of the interesting points of the community of Yako is that most of the local population is aware of the fact that the *moringa oleifera* species houses “special” properties that can be used to “clean” water (some sources even suggest that the use of moringa oleifera for this purpose was practiced in Sudan and Egypt as long as five centuries ago). Such folkloric knowledge, however, has never been applied in practical or tangible form in modern times. With this in mind, this study can therefore be viewed as being, on the one hand, innovative on practical level, whilst on the other hand already quite familiar to most local populations on an anecdotal level.

Nowadays several pilot plants for water treatment already operate in different places of Africa which use the extract of Moringa Oleifera seeds as coagulant. In 2010 a pilot plant of 10,000 L per day of capacity was started up in Zaria (Nigeria) to supply the Ahmadu Bello University [9]. Previously, in 2006 it were conducted tests of coagulation flocculation with Moringa Oleifera in the drinking water treatment plant of Ggaba II in Kampala (Uganda) [10].

In the field of water management, in the district of Yako there are 122 excavated wells used primarily for irrigation purposes, although some of them are in fact utilized for human consumption despite the bacterial contamination observed in analyzed water samples. There are also a number of perforated fresh water wells from which water is supplied through the use of hand pumps. These wells, installed primarily by ONEA (the national water and sanitation authority), in general show satisfactory water quality results based on our analysis. However, there are several of these that fall notably below desirable water quality standards. The district of Yako currently has eight water reservoirs, which are exploited mainly for agricultural activities. Nevertheless, despite the contamination provoked by these and other activities, it is not infrequent that such waters are also used to satisfy the growing demand for potable water.

2. OBJECTIVES

The focal point of this study is the design of a plant to purify reservoir water using natural products, guaranteeing access to potable water for 1000 people in the location of Yako, Burkina Faso.

3. CASE STUDY

A team from the Polytechnic University of Catalonia (UPC)-Barcelona Tech, with the support of the Centre for International Cooperation for Development (CCD), recently travelled to Yako, Burkina Faso with the aim of conducting a field study to determine the most appropriate location for installing the water purification plant. Likewise, an in-depth assessment was carried out of the water quality of specified areas. In the area of Yako there are eight reservoirs of which only one, the Kanazoé dam, retains extractable water throughout the year. Water samples from this dam as well as an excavated well located in the immediate vicinity were collected and analyzed. The main results of these analyses are presented in Table 1. These results were compared with international standards for drinking water as established by the World Health Organization. In this table it can be observed how both the Kanazoé water reservoir and the excavated well present turbidity levels which exceed WHO limits [11]. Likewise, the samples also exceed international limits in terms of pathogenic microorganisms. On the other hand, nitrate pollution resulting from the use of fertilizer and/or other sources appears to be minimal and the presence of ions in the form of hardness, alkalinity, and salinity (expressed as conductivity), was moderate.

Table 1. *Water quality of the Kanazoé reservoir with respect to the WHO international standards for potable water.*

Source	Parameter					
	Nitrates (mg/L)	Conductivity (µs/cm)	Turbidity (NTU)	Hardness (mg/L)	Alcalinity (mg/L)	Total Coliforms
Excavated well	0	510	27	60	40	>1/100ml
Reservoir	0	340	53	50	40	>1/100ml
International Standards	50	2,000	5	100-300	1,000	<1/100ml

Taking these factors into account, the water purification plant design must ensure the removal of water turbidity, followed by the elimination of pathogenic microorganisms through water disinfection.

Figure 1 presents a flow diagram of the processes to be executed by the purification plant.

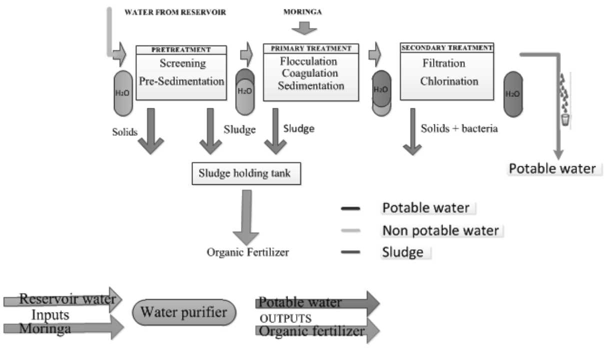

Figure 1. *Process diagram of the purification plant.*

The purification process of the reservoir begins with a pre-treatment phase. This consists of the elimination of bulky material as well as heavy suspended solids of high sedimentability by way of pre-sedimentation in a holding tank. In the next phase of treatment, the water undergoes a primary treatment designed to reduce turbidity via the use of *moringa oleifera.* This natural coagulant-flocculant interacts with suspended particulates to form larger coagula and thus provoke their sedimentation in the sedimentation chamber.

During the final phase, the clarified water passes through a series of filters and undergoes a posterior disinfection via chlorination.

4. DESIGN OF THE WATER TREATMENT PLANT

The design of the purification plant is established based on the premise that it will be constructed in Western Africa. Concretely it will be in an impoverished region where economic and material resources are scarce, of difficult accessibility and the supply of energy from the nearest electrical grid is nonexistent. The labor force is primarily unskilled and the climatic conditions are extreme; high temperature and seasons of torrential rains. All of these factors thus amount to considerable limitations in the feasibility of a wide array of water management solutions.

The UPC team held several meetings and workshops with both local engineering BERACIL as with the counterpart (ODE), as well as with local authorities (technical and political) in order to know the climate, economic and socio cultural factors to be taken into account in the design and location of the water treatment plant. The main conclusions obtained in these meetings were:

- Due to the high seasonality of rainfall the treatment plant must take water from a reservoir that contains water the whole year. In the municipalities of Yako and Gompomssom the dam of Kanazoé fulfill this condition.
- The plant will be located in an area safe from floods during the rainy season.
- Construction with local materials. Some modifications were made according with local infrastructures: metal roof, metallic structure of the tower for the raw water tank. The participation of local workshops ensures the proper maintenance of the installation.
- The building in concrete of the initial tank of raw water was discarded due to the excessive weight that the tower should support. It were obtained contacts of local suppliers of PVC.
- The walls of the plant will have lateral openings for better ventilation.
- The potable water tanks shall be located in a square to promote the personal relationship among women, who generally has the mission of providing water to his house.
- The operation and maintenance of the plant does not require of technical specialization and It can be carried out by local population.

From an energy standpoint, the plant is designed in such a way that it would only require the installation of a solar panel. The energy of the appropriately dimensioned solar panel would suffice for the energy required to raise the untreated water to an elevated holding tank, from which the water is fed by gravity into the rest of the plant.

The plant is divided into six sectors; screening cage, pump housing, water tower, treatment plant housing, sludge pit, square for water storage tanks. These sectors are illustrated in the diagram of sectors, systems and apparatus in Figure 2.

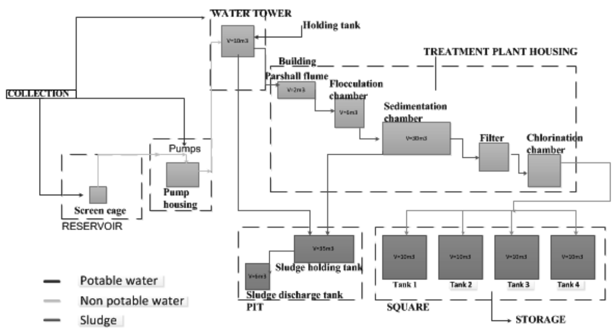

Figure 2. *Diagram of sectors, systems and apparatus of the purification plant.*

The principal components and apparatus of the purification plant are described below.

4.1 Screening cage

A flexible tube connects the reservoir to the pumping system. A screening cage will be coupled to the pipe intake so as to prevent debris such as branches, solid waste or any bulky materials from entering the plant. This screen cage is to be of the cubic dimensions of 30x30x30 cm, with a mesh diameter of 5 mm and 30 mm partitions between each.

4.2 Pump housing

Taking into account the lack of a power supply from an electrical grid, alternative energy sources have been opted for, with solar being the most viable option, especially considering the average daily solar radiation received in the area. Wind energy had also been considered initially, however, anemometric data of the region proved this option to be less favorable.

The primary pumping system comprises a solar panel which feeds either into an energy storage battery or directly into a pump. The recommended pump model is a surface PS600 BADU Top12 centrifuge pump, solar powered and with a flow rate of up to 15 m^3/hr.

Two back-up pumping systems are also proposed as a means of providing alternatives in situations of pump malfunction or breakdown of the main system. On the one hand there is the option of a manual pump connected in parallel to the electric pump. On the other hand there is a pulley system installed on the upper part of the water tower that could be utilized to fill the holding tank by way of manually raising the water in a bucket.

4.3 Water tower

The preliminary water holding tank which has a total volume of 10 m^3, is supported at a height of 12 m on the platform of a metal-framed tower. This height ensures that the water to be treated can be fed by gravity into each of the treatment phases of the plant and thus eliminate the need for further consumption of electrical energy in the turbidity removal phase.

The hydraulic retention time in the preliminary holding tank will facilitate the pre-sedimentation of the larger suspended particles. For this reason a purge line will be installed at the bottom of the tank so as to channel the sedimented solids directly to the sludge holding tank.

4.4 Treatment plant housing

All components of the processes of coagulation, flocculation, filtration and chlorination will be enclosed in a building protecting them from the elements, animals as well as potential acts of vandalism.

The walls and roof will be composed of handmade clay bricks manufactured by local craftsmen. The roofing structure will be made using 14-16 mm steel rod welded by local blacksmiths just prior to being installed. A corrugated steel sheet will be fixed onto the iron rod frame, protecting the building interior from the elements. Iron windows installed at various points of the building periphery will guarantee the continuous flow of air throughout the facility, reducing the indoor temperature.

Parshall Flume

The parshall flume is a rapid hydraulic mixer in which the process of coagulation will take place by adsorption. The principal advantage of such an installation is that it requires no mechanical components. It consists of a flume or channel made of concrete within a variable square section. In this channel mixing takes place as a result of the combination of the turbulence generated as the water flows through the points of narrowing and the lift produced in the variable section of the channel. It has a length of 10 m and a width of 1m, and a volume of 2 m^3.

The dosage of coagulant is performed via a hopper containing the *moringa oleifera* powder. The power is added via a submerged, perforated tube placed in the flume at the point of rise. As the flow of water passes over the tube the mixing of the coagulant takes place with the suspended particulates in the water. The dosage of coagulant can be optimized by altering the number and diameter of the orifices in the tube. This system, as with the rest of the plant, is based on simple gravity-based feed which does not require the use of an electric dosage pump nor does it need significant maintenance.

The use of *moringa oleifera* powder entails a total replacement of conventional synthetic coagulants ($FeCl_3$, $Al_2(SO_4)_3$ etc,) and the procedure for preparing the seeds is straightforward: the seed pods dry naturally while still on the tree; they are then easily removed from the pods and are ground and sieved using the same techniques used in local corn or millet flour production. Once finely sieved and mixed with water, the powder produces soluble proteins with a net positive charge once mixed with water. The dosage of this moringa protein solution (typically a concentration of between 1-3%) functions as a polyelectrolyte during the water treatment process.

Whilst synthetic coagulants only function well at restricted ranges of pH, *moringa oleifera* based coagulant has been proven to be effective regardless of pH of the water in question. This is an added advantage for zones of limited resources where the likelihood of being able to effectively regulate water pH prior to coagulation may be very limited or nonexistent [12].

Clarifier / Flocculation Chamber

A hydraulic flow-through flocculator is used because of its simplicity and autonomy. Specifically, it is a helicoidal flow flocculator called a spiral blade or tangential flow clarifier that uses hydraulic energy to generate helicoidal movement in the water induced by its tangential entry into the flocculation chamber. The clarifier will consist of four parallel chambers made *in situ* of concrete. The first and second chambers, as with the third and fourth, are connected by way of passages which are submerged orifices with a total volume of 6 m^3.

Sedimentation chamber:

Floccules formed in the clarifier finally sediment to the bottom of the sedimentation chamber where they directed towards the sludge put via an extraction tube. The sedimentation chamber is a rectangular tank which is designed to facilitate uniform flow movement of the water with as few alterations as possible.

The dimensions of the sedimentation chamber are 9.5 m in length, 2 m in width and an average depth of 1.5 m, occupying a surface of 19 m^2 and with a capacity of 28.5 m^3. It will be made of reinforced concrete in situ.

Filter:

Once the sedimentation process is complete there may still be particles in the water that need to be removed. For this purpose a disk filter is installed. Such a filter can be hand-crafted, using disks of perforated plastic and PVC tubes. This concept is easily duplicable, easy to dismount, clean and is also very economical.

Chlorination set

With the water free of suspended solids, the next phase consists of disinfection. Chemical disinfection by way of chlorination is selected given that most other disinfection methods studied are more expensive as well as more complex to operate reliably.

The system installed uses electrolysis to generate *in situ* the chlorine necessary for the treatment plant. This therefore eliminates the need for resorting to external supplies of chlorine. The electrolysis system requires a 12 V battery (rechargeable using a portable solar panel), and common table salt as the only raw material. Chlorine is generated in its gaseous state via the electrolysis process and is "drawn" into the incoming stream of water via the vacuum created in a venturi tube. The system generates a minimum concentration of chlorine of 0.2 mg/L which can be increased to 0.5 mg/L of chloride by recirculation of the treated water.

4.5 Sludge holding tank

The sludge generated in the process will be collected in an excavated pit divided into two parts: a sludge holding tank and a discharge tank which collects the liquid phase decanted from the sludge holding tank.

The sludge tank has a rectangular bottom and reclining floor with a length of 5 m, a width of 2 m and a depth of 3.5 m. It is made *in situ* of reinforced concrete and it has a total sludge storage volume of 35 m^3.

The liquid phase discharge tank is parallel to the sludge tank, separated by a 1.5 m reinforced concrete panel and has a total volume of 6 m^3. The function of this discharge chamber is to collect the water that is inevitably expelled from the plant together along with the sludge of the plant. When the sludge holding tank is full, the liquid fraction remains on the top layer whilst the solid fraction settles to the bottom and is channeled to a sludge storage tank.

The task of extracting sludge from the storage tank will be done by small tanker trucks which will transport sludge from the plant which could then be employed as fertilizer in local agricultural activities.

4.6 Potable water storage tanks

Four one piece, 10 m^3 polyethylene storage tanks will be used to store the purified water. These tanks are rust proof, high resistance, corrugated, cylindrical and are easy to clean and maintain. The typical life span of such units is 30 years. Each tank is covered with a polyurethane insulation so as to minimize the increase in the water temperature, given that such tanks will often be exposed to high diurnal temperatures. Figure 3 shows a schematic diagram of all of the components and installations of the water purification plant.

5. CONCLUSIONS

This study shows the design of a water purification plant of reservoir water destined for a rural population of 1,000 people in Burkina Faso. The plant considers the socio-economic reality of the zone, in that the installations are easy to construct and maintain, low cost and don´t require the use of mechanical or electronic systems.

The only energy requirement of the primary and secondary treatment phases of the plant is a solar panel which is required to power the centrifugal pump which feeds water into the initial elevated holding tank. From this point on, the plant operates by way of gravitational energy.

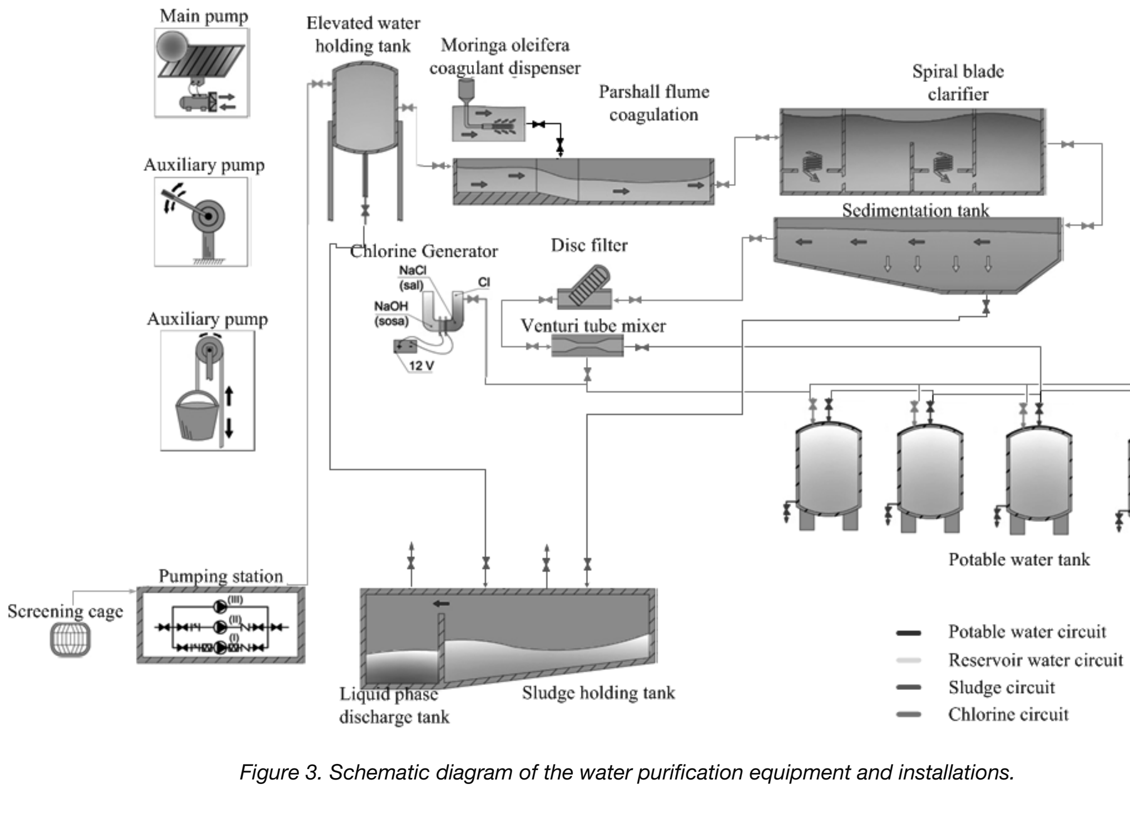

Figure 3. Schematic diagram of the water purification equipment and installations.

The use of the seeds of *moringa oleifera*, a plant cultivated in the region, is proposed as a substitute for the chemical coagulants for the elimination of turbidity in water. Lastly, the disinfection of the water is carried out by way of electro-generated chlorine using a brine solution with a 12 V battery also rechargeable using a solar panel.

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